CHAPTER 1

INTRODUCTION AND PROCESS CAPABILITIES

1.1 Purpose

The purpose of this manual is to provide criteria and supporting information for planning and process design of land treatment systems. Recommended procedures for planning and design are presented along with state-of-the-art information on treatment performance, energy considerations, and health and environmental effects.

Cost curves are not included in this manual, although some cost information is included in Chapter 2. Costs for planning may be obtained from cost curves in references [1, 2] , or through the CAPDET computer system developed by the Corps of Engineers for EPA. CAPDET computer terminals are available in EPA regional offices.

This document is a revision of the Process Design Manual for Land Treatment of Municipal Wastewater sponsored by the U.S. Environmental Protection Agency, U.S. Army Corps of Engineers, and U.S. Department of Agriculture, and published in 1977. The revision is necessary because of the large amount of research data, criteria, and operating experience that has become available in recent years. As a result of PL 92-500 and PL 95-217, the interest in and use of land treatment concepts has increased significantly and is expected to continue to increase.

1.2 Scope

Land treatment is defined as the controlled application of wastewater onto the land surface to achieve a designed degree of treatment through natural physical, chemical, and biological processes within the plant-soil-water matrix.

The scope of this manual is limited to the three major land treatment processes:

- Slow rate (SR)
- Rapid infiltration (RI)
- Overland flow (OF)

These processes are defined later in this chapter and discussed in detail in the design chapters. The titles were adopted for the original 1977 manual to reflect the rate of wastewater application and the flow path within the process. Prior to the 1977 manual, the term “irrigation” was often used to describe the slow rate process. The present term was chosen to focus attention on wastewater treatment rather than on irrigation of crops.

Subsurface systems, wetlands, and aquaculture were discussed briefly in the 1977 manual but are deleted here since they are now covered in detail in other documents [3, 4]. Land application of sludge, injection wells, evaporation ponds, and other forms of treatment or disposal that involve the soil matrix are also excluded.

Most of the information in this manual is applicable to medium-to-large systems. For small systems, up to 1,000 m^3/d (250,000 gal/d), many of the design procedures can be simplified. Special considerations for these small systems and a number of typical examples are discussed in Chapter 7. Case studies for larger systems are available in other publications [5-9] . This manual addresses land treatment of municipal wastewater, not industrial wastes. Under controlled conditions, however, land treatment of many types of industrial wastewaters and even hazardous materials can be both technically and economically feasible.

Although the principal focus in the manual is on the three basic processes (SR, RI, OF), the possibility of combining two or more of the concepts in a continuous system should not be overlooked. Overland flow could be a preapplication step for either SR or RI, or different processes could be used in cold and warm weather.

1.3 Treatment Processes

Typical design features for the three land treatment processes are compared in Table 1-1. The major site characteristics are compared for each process in Table 1-2. These are desirable characteristics and not limits to be adhered to rigorously, as discussed in Chapter 2.

The expected quality of treated water for biochemical oxygen demand (BOD), suspended solids (SS), nitrogen, phosphorus, and fecal coliforms is presented for each process in Table 1-3. The average and expected upper range values are valid for the travel distances and applied wastewater as indicated. The fate of these materials (plus metals, viruses, and trace organics) is discussed in the chapters that follow.

TABLE l-l
COMPARISON OF TYPICAL DESIGN FEATURES FOR LAND TREATMENT PROCESSES

Feature	Slow rate	Rapid infiltration	Overland flow
Application techniques	Sprinkler or surface[a]	Usually surface	Sprinkler or surface
Annual loading rate, m	0.5—6	6—125	3—20
Field area required, ha[b]	23—280	3—23	6.5-44
Typical weekly loading rate, cm	1.3-10	10—240	6-40[c]
Minimum presoplication treatment provided in the United States	Primary sedimentation d	Primary sedimentatione	Grit removal and comminutione
Disposition of applied wastewater	Evapotranspiration and percolation	Mainly percolation	Surface runoff and evapotranspiration with some percolation
Need for vegetation	Required	Optional	Required

a. Includes ridge—and—furrow and border strip.

b. Field area in hectares not including buffer area, roads, or ditches for 3,785 m^3/d (l Mgal/d) flow.

c. Range includes raw wastewater to secondary effluent, higher rates for higher level of preapplication treatment.

d. With restricted public access; crops not for direct human consumption,

e. With restricted public access.

Note: See Appendix G for metric conversions.

TABLE 1-2
COMPARISON OF SITE CHARACTERISTICS FOR LAND TREATMENT PROCESSES

	Slow rate	Rapid infiltration	Overland flow
Grade	Less than 20% on cultivated land; lees than 40% on noncultivated land	Not critical; excessive grades require much earthwork	Finish slopes 2-8%[a]
Soil permeability	Moderately slow to moderately rapid	Rapid (sands, sandy loams)	Slow (clays, silts, and soils with impermeable barriers)
Depth to ground water	0.6—1 m (minimum)[b]	1 m during flood cycle[b]; 1.5—3 m during drying cycle	Not critical[c]
Climatic restrictions	Storage often needed for cold weather and during heavy precipitation	None (possibly modify operation in cold weather)	Storage usually needed for cold weather

a. Steeper grades might be feasible at reduced hydraulic loadings.

b. Underdrains can be used to maintain this level at sites with high ground water table.

c. Impact on ground water should be considered for more permeable soils.

TABLE 1-3
EXPECTED QUALITY OF TREATED WATER
FROM LAND TREATMENT PROCESSES[a]
mg/L Unless Otherwise Noted

Constituent	Slow rate[b] Average	Slow rate[b] Upper range	Rapid infiltration[c] Average	Rapid infiltration[c] Upper range	Overland flow[d] Average	Overland flow[d] Upper range
BOD	<2	<5	5	<10	10	<15
Suspended solids	<1	<5	2	<5	10	<20
Ammonia nitrogen as N	<0.5	<2	0.5	<2	<4	<8
Total nitrogen as N	3[e]	<8[e]	10	<20	5[f]	<10[f]
Total phosphorus as p	<0.1	<0.3	1	<5	4	<6
Feral coliforms, No./100 mL	0	<10	10	<200	200	<2,000

a. Quality expected with loading rates at the mid to low end of the range shown in Table 1—1.

b. Percolation of primary or secondary effluent through 1.5 m (5 ft) of unsaturated soil.

c. Percolation of primary or secondary effluent through 4.5 m (15 ft) of unsaturated soil; phosphorus and feral coliform removals increase with distance (see Tables 5—3 and 5—6).

d. Treating comminuted, screened wastewater using a slope length of 30—36 m (100—120 ft)

e. Concentration depends on loading rate and crop.

f. Nigher values expected when operating through a moderately cold winter or when using secondary effluent at high rates.

1.4 Slow Rate Process

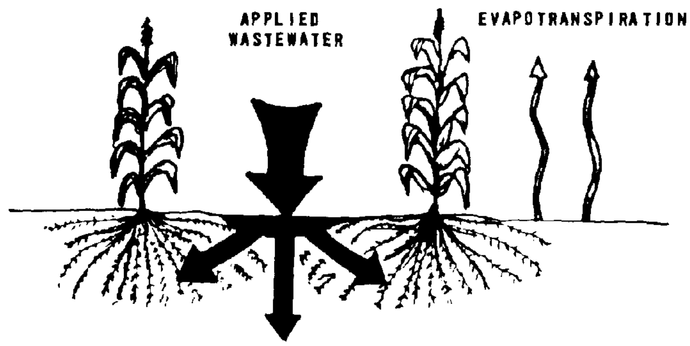
Slow rate land treatment is the application of wastewater to a vegetated land surface with the applied wastewater being treated as it flows through the plant-soil matrix. A portion of the flow percolates to the ground water and some is used by the vegetation. Offsite surface runoff of the applied water is generally avoided in design. Schematic views of the typical hydraulic pathways for SR treatment are shown in Figure l-l(a)(b)(c). Surface application techniques include ridge-and-furrow and border strip flooding. Application by sprinklers can be from fixed risers or from moving systems, such as center pivots.

1.4.1 Process Objectives

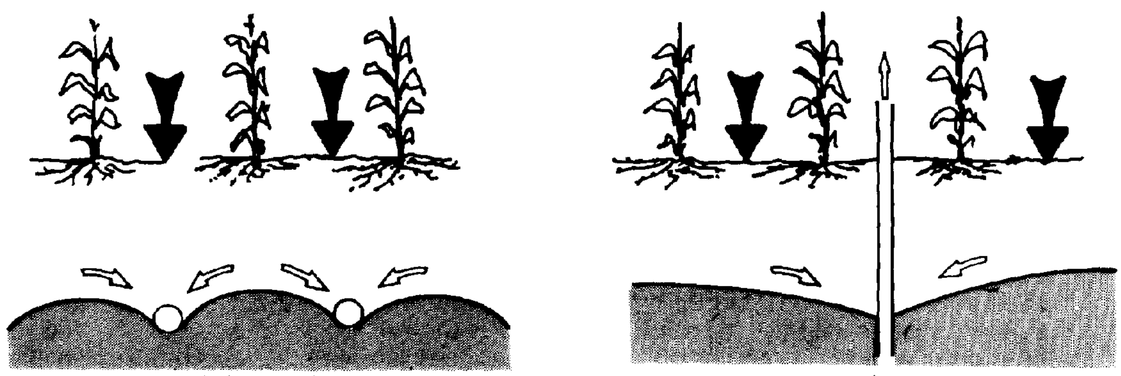
Slow rate processes can be operated to achieve a number of objectives including:

1. Treatment of applied wastewater

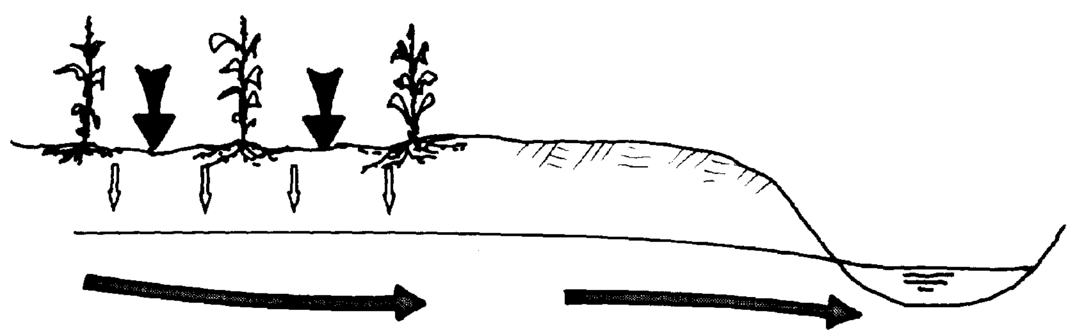
2. Economic return from use of water and nutrients to produce marketable crops (irrigation)



(a) APPLICATION PATHWAY



(b) RECOVERY PATHWAYS



(c) SUBSURFACE PATHWAY

FIGURE 1-1
SLOW RATE HYDRAULIC PATHWAYS

3. Water conservation, by replacing potable water with treated effluent, for irrigation

4. Preservation and enlargement of greenbelts and open space

When requirements are very stringent for nitrogen, phosphorus, BOD, 55, pathogens, metals, and trace organics, they can be met usually with SR treatment. Nitrogen is often the limiting factor for SR design because of EPA drinking water limits on ground water quality. In arid regions, however, maintaining chlorides and total dissolved salts at acceptable levels for crop production may be limiting. Management approaches to meet these objectives within the SR process are discussed under the topics (1) wastewater treatment, (2) agricultural systems, (3) turf systems, and (4) forest systems.

1.4.1.1 Wastewater Treatment

When the primary objective of the SR process is treatment, the hydraulic loading is usually limited either by the hydraulic capacity of the soil or the nitrogen removal capacity of the soil-vegetation matrix. Underdrains are sometimes needed for development of sites with high ground water tables, or where perched water tables or impermeable layers prevent deep percolation. Perennial grasses are often chosen for the vegetation because of their high nitrogen uptake, a longer wastewater application season, and the avoidance of annual planting and cultivation. Corn and other crops with higher market values are also grown on systems where treatment is the major objective. Muskegon, Michigan [1011 is a noted example in the United States with over 2,000 hectares (5,000 acres) of corn under cultivation.

1.4.1.2 Agricultural Systems

In the more arid western portions of the United States, the water itself (not the nutrient content) is the most valuable component of the wastewater. Crops are selected for their maximum market potential and the least possible amount of wastewater needed for irrigation. Application rates between 2 to 8 cm/wk (0.8 to 3.1 in./wk) are common. This is enough water to satisfy crop needs, plus a leaching requirement to maintain a desired salt balance in the root zone.

In the more humid east, the water component may be critical at certain times of the year and during extended drought periods, but the nutrients in the wastewater are the most valuable component. Systems are designed to promote the nutrient uptake by the crop and increase yields. At

Muskegon, Michigan, for example, corn yields in 1977 were 6.5 m^3/ha (75 bushels per acre) compared to 5.2 m^3/ha (60 bushels per acre) for the nonwastewater farming in the same area [10]. Regardless of geographical location, wastewater irrigation can benefit crop production by providing nutrients and moisture.

1.4.1.3 Turf Systems

Golf courses, parks, and other turfed areas are used in many parts of the United States for SR systems, thus conserving potable water supplies. These areas have considerable public access and this requires strict control of pathogenic organisms. This control can be achieved by disinfection or by natural processes in biological treatment ponds or storage ponds.

1.4.1.4 Forest Systems

Slow rate forest systems exist in many states including Oregon, Washington, Michigan, Maryland, Florida, Georgia, Vermont, and New Hampshire. In addition, experimental systems in a variety of locations are being studied extensively to determine permissible loading rates, responses of various tree species, and environmental effects (see Chapter 4).

Forests offer several advantages that make them desirable sites for land treatment:

1. Forest soils often exhibit higher infiltration rates than agricultural soils.

2. Site acquisition costs for forestland are usually lower than site acquisition costs for prime agricultural land.

3. During cold weather, soil temperatures are often higher in forestlands than in agricultural lands.

4. Systems can be developed on steeper grades in the forest as compared to agricultural sites.

The principal limitations to the use of wastewater for forested SR systems are:

1. Water needs and tolerances of some existing trees may be low.

2. Nitrogen removals are relatively low unless young, developing forests are used or conditions conducive to denitrification are present.

3. Fixed sprinklers, which are expensive, are usually necessary.

4. Forest soils may be rocky or very shallow.

1.4.2 Treatment Performance

The SR process is capable of producing the highest degree of wastewater treatment of all the land treatment systems. The quality values shown in Table 1-3 can be expected for most well-designed and well-operated systems.

Organics are reduced substantially by SR land treatment within the top 1 to 2 cm (0.4 to 0.8 in.) of soil. Filtration and adsorption are the initial steps in BOD removal, but biological oxidation is the ultimate treatment mechanism. Filtration is the major removal mechanism for suspended solids. Residues remaining after oxidation and the inert solids become part of the soil matrix.

Nitrogen is removed primarily by crop uptake, which varies with the type of crop grown and the crop yield. To remove the nitrogen effectively, the crop must be harvested. Denitrification can also be significant, even if the soil is in an aerobic condition most of the time. Other nitrogen removal mechanisms include ammonia volatilization and storage in the soil.

Phosphorus is removed from solution by fixation processes in the soil, such as adsorption and chemical precipitation. Removal efficiencies are generally very high for SR systems and are more dependent on the soil properties than on the concentration of the phosphorus applied. Residual phosphorus concentrations in the percolate will generally be less than 0.1 mg/L [11]. A small but significant portion of the phosphorus applied is taken up and removed with the crop.

1.5 Rapid Infiltration Process

In RI land treatment, most of the applied wastewater percolates through the soil, and the treated effluent drains naturally to surface waters or joins the ground water. The wastewater is applied to moderately and highly permeable soils (such as sands and loamy sands), by spreading in basins or by sprinkling, and is treated as it travels through the soil matrix. Vegetation is not usually planned, but there are some exceptions, and emergence of weeds and grasses usually does not cause problems.

The schematic view in Figure 1-2(a) shows the typical hydraulic pathway for rapid infiltration. A much greater portion of the applied wastewater percolates to the ground water than with SR land treatment. There is little or no consumptive use by plants. Evaporation ranges from about 0.6 in/yr (2 ft/yr) for cool regions to 2 in/yr (6 ft/yr) for hot arid regions. This is usually a small percentage of the hydraulic loading rates.

In many cases, recovery of renovated water is an integral part of the system. This can be accomplished using underdrains or wells, as shown in Figure 1-2(b). In some cases, the water drains naturally to an adjacent surface water (Figure 1-2(c)). Such systems can provide a higher level of treatment than most mechanical systems discharging to the same surface water.

1.5.1 Process Objectives

The objective of RI is wastewater treatment. Uses for the treated water can include:

1. Ground water recharge

2. Recovery of renovated water by wells or underdrains with subsequent reuse or discharge

3. Recharge of surface streams by interception of ground water

4. Temporary storage of renovated water in the aquifer

If ground water quality is being degraded by saltwater intrusion, ground water recharge by RI can help to create a barrier and protect the existing fresh ground water. In many cases, the major treatment goal is conversion of ammonia nitrogen to nitrate nitrogen prior to discharge to surface waters. The RI process offers a cost-effective method for achieving this goal with recovery or recharge as described in items 2 and 3 above. Return of the renovated water to the surface by wells, underdrains, or ground water interception may be necessary or advantageous when discharge to a particular surface water body is controlled by water rights, or when existing ground water quality is not compatible with expected renovated water quality. At Phoenix, Arizona, for example, renovated water is being withdrawn by wells to allow reuse of the water for irrigation.

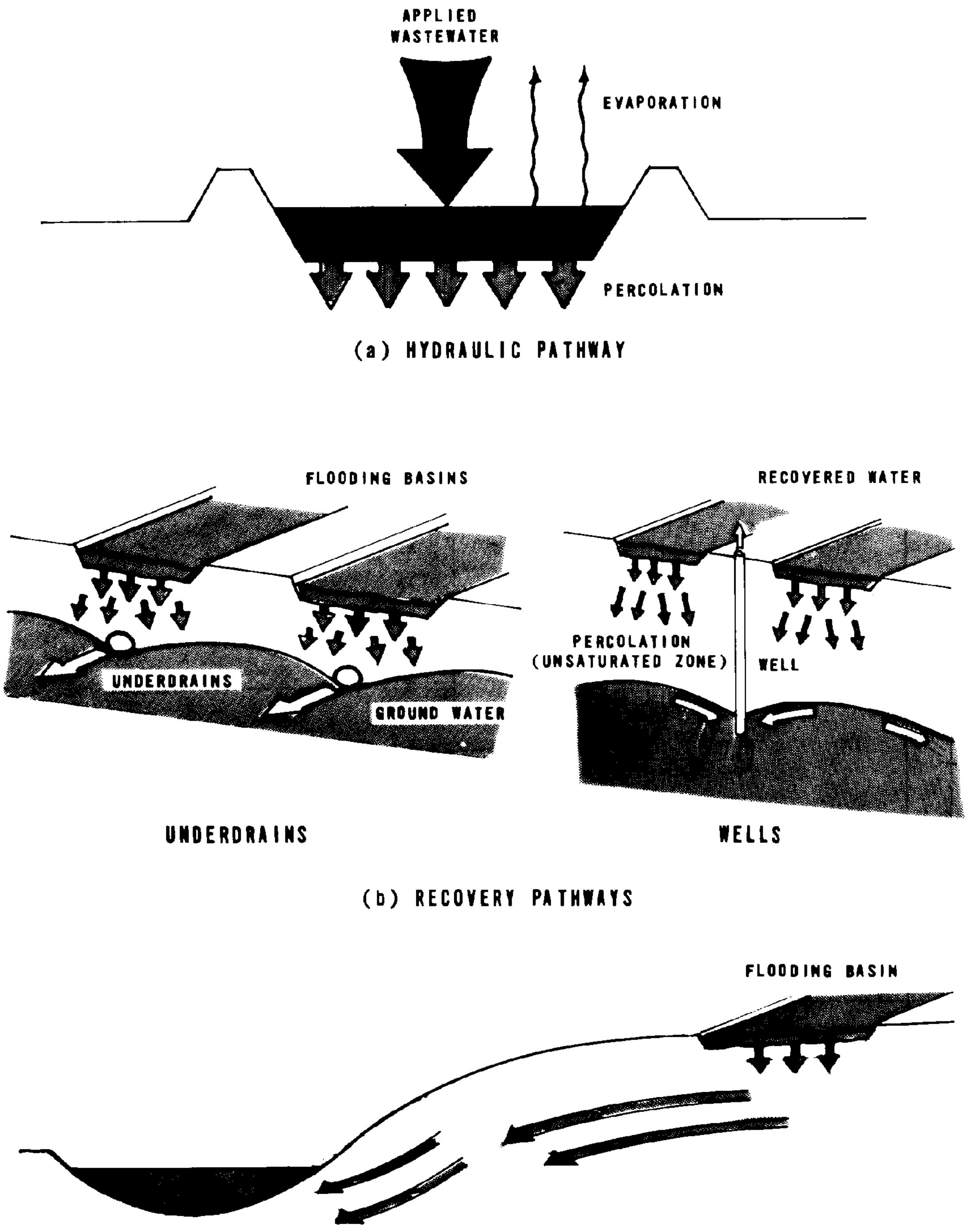


FIGURE 1-2
RAPID INFILTRATION HYDRAULIC PATHWAYS

1.5.2 Treatment Performance

Removals of wastewater constituents by the filtering and straining action of the soil are excellent. Suspended solids, BOD, and fecal coliforms are almost completely removed.

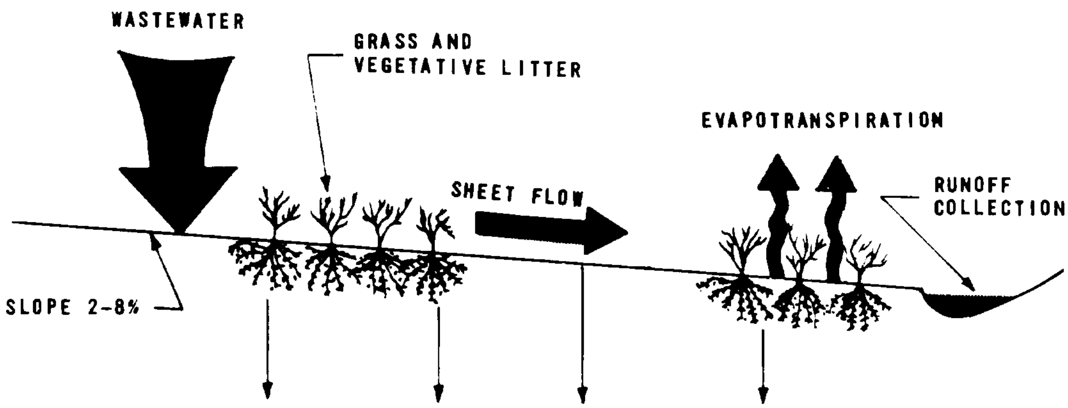
Nitrification of the applied wastewater is essentially complete when appropriate hydraulic loading cycles are used. Thus, for communities that have ammonia standards in their discharge requirements, RI can provide an effective way to meet such standards.

Generally, nitrogen removal averages 50% unless specific operating procedures are established to maximize denitrification. These procedures include optimizing the application cycle, recycling the portions of the renovated water that contain high nitrate concentrations, reducing the infiltration rate, and supplying an additional carbon source. Using these procedures in soil column studies, average nitrogen removals of 80% have been achieved. Nitrogen removal by denitrification can be significant if the hydraulic loading rate is at the mid range or below the values in Table 1-1 and the DOD to nitrogen ratio is 3 or more.

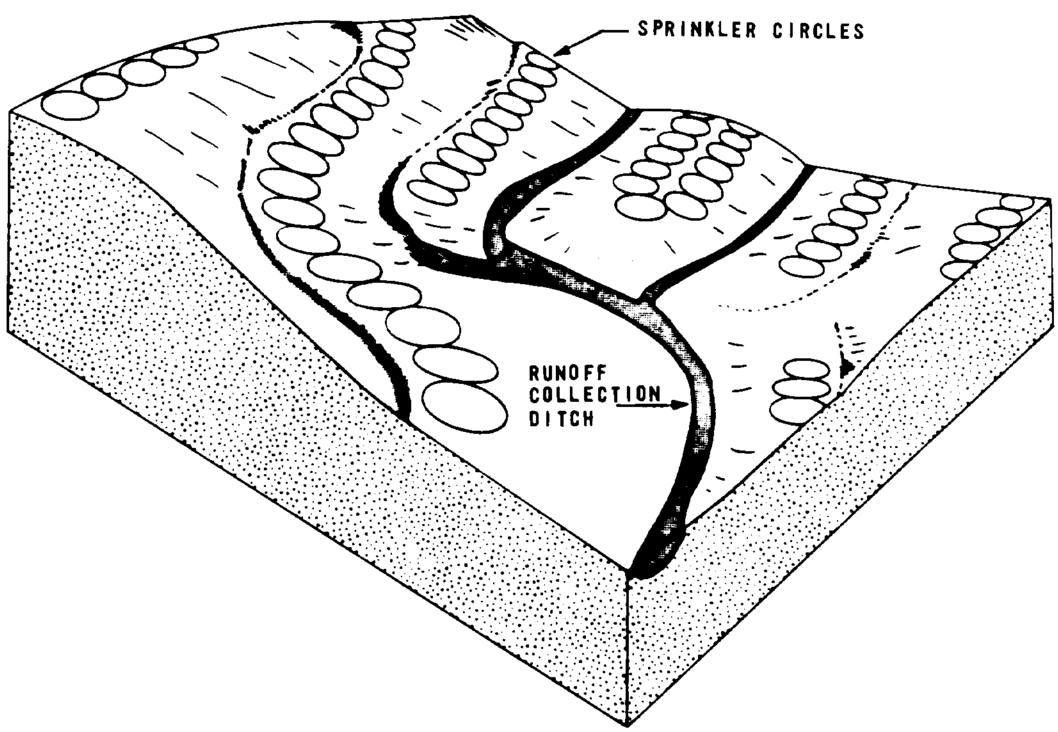
Phosphorus removals can range from 70 to 99%, depending on the physical and chemical characteristics of the soil. As with SR systems, the primary removal mechanism is adsorption with some chemical precipitation, so the long-term capacity is limited by the mass and the characteristics of soil in contact with the wastewater. Removals are related also to the residence time of the wastewater in the soil, the travel distance, and other climatic and operating conditions.

1.6 Overland Flow Process

In OF land treatment, wastewater is applied at the upper reaches of grass covered slopes and allowed to flow over the vegetated surface to runoff collection ditches. The OF process is best suited to sites having relatively impermeable soils. However, the process has been used with success on moderately permeable soils with relatively impermeable subsoils. The wastewater is renovated by physical, chemical, and biological means as it flows in a thin film down the length of the slope. A schematic view of OF treatment is shown in Figure 1-3(a), and a pictorial view of a typical system is shown in Figure 1-3(b). As shown in Figure 1-3(a), there is relatively little percolation involved either because of an impermeable soil or a subsurface barrier to percolation.



(a) HYDRAULIC PATHWAY



(b) PICTORIAL VIEW OF SPRINKLER APPLICATION

FIGURE 1-3
OVERLAND FLOW

Interest by municipalities and design engineers has spurred research and demonstration projects in South Carolina, New Hampshire, Mississippi, Oklahoma, Illinois, and California. Cold-weather operation has been demonstrated through several winters at Hanover, New Hampshire. Rational design equations have been developed based on research at Hanover and at Davis, California.

1.6.1 Process Objectives

The objectives of OF are wastewater treatment and, to a minor extent, crop production. Treatment objectives may be either:

1. To achieve secondary effluent quality when applying screened raw wastewater, primary effluent, or treatment pond effluent.

2. To achieve high levels of nitrogen, BOD, and SS removals.

Treated water is collected at the toe of the OF slopes and can be either reused or discharged to surface water. Overland flow can also be used for the preservation of greenbelts.

1.6.2 Treatment Performance

Biological oxidation, sedimentation, and filtration are the primary removal mechanisms for organics and suspended solids.

Nitrogen removals are a combination of plant uptake, denitrification, and volatilization of ammonia nitrogen. The dominant mechanism in a particular situation will depend on the forms of nitrogen present in the wastewater, the amount of carbon available, the temperature, and the rates and schedules of wastewater application. Permanent nitrogen removal by the plants is only possible if the crop is harvested and removed from the field. Ammonia volatilization can be significant if the pH of the wastewater is above 7. Nitrogen removals usually range from 75 to 90% with the form of runoff nitrogen dependent on temperature and on application rates and schedule. Less removal of nitrate and ammonium may occur during cold weather as a result of reduced biological activity and limited plant uptake.

Phosphorus is removed by adsorption and precipitation in essentially the same manner as with the SR and RI methods. Treatment efficiencies are somewhat limited because of the limited contact between the wastewater and the adsorption sites within the soil. Phosphorus removals usually range from 50 to 70% on a mass basis. Increased removals may be obtained by adding alum or ferric chloride to the wastewater just prior to application on the slope.

1.7 Combination Systems

In areas where effluent quality must be very good, or where a high degree of treatment reliability must be maintained, combinations of land treatment processes may be desirable. For example, either an SR, RI, or a wetlands treatment system could follow an OF system and would result in better overall treatment than the OF alone. In particular, these combinations could be used to improve BOD, suspended solids, nitrogen, and phosphorus removals.

Similarly, OF could be used prior to RI to reduce nitrogen levels to acceptable levels. This combination was demonstrated successfully in a pilot scale study at Ada, Oklahoma, using screened raw wastewater for the OF portion [12]

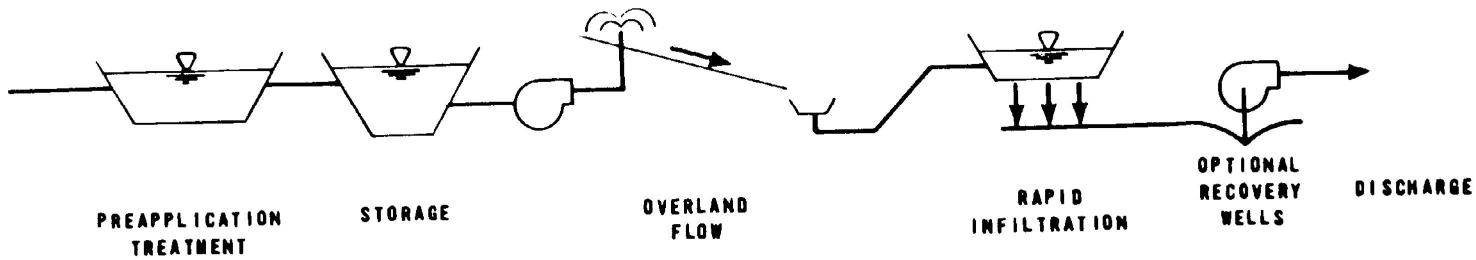
Rapid infiltration may also precede SR land treatment. In this combination, renovated water quality following RI is expected to be high enough that even the most restrictive requirements regarding the use of renovated water on food crops can be met. Also, the ground water aquifer can be used to store renovated water to correspond with crop irrigation schedules. Some of these combinations are shown schematically in Figure 1-4.

1.8 Guide to Intended Use of the Manual

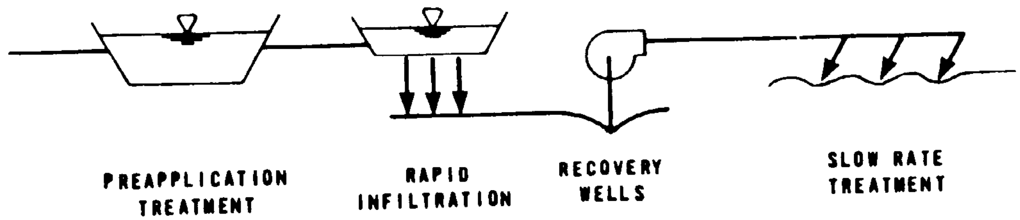
This manual is organized similarly to the original 1977 edition except that the design examples are included as appendixes. Completely new features in this manual are chapters on energy, and health and environmental effects.

Chapters 2 through 6 follow, in sequence, a logical procedure for planning and design of land treatment systems. The procedure commences (Chapter 2) with screening of the entire study area to identify potential land treatment sites. The Phase 1 planning is based on existing information and data on land use, water rights, topography, soils, and geohydrology. If potentially suitable sites exist, the Phase 2 planning then involves detailed site investigations (Chapter 3) to determine process suitability and preliminary design criteria (Chapters 4, 5, and 6).

Process selection for a particular situation is influenced by health and environmental issues (Chapter 9) and by energy



a) OVERLAND FLOW FOLLOWED BY RAPID INFILTRATION



b) RAPID INFILTRATION FOLLOWED BY SLOW RATE TREATMENT

FIGURE 1-4
EXAMPLES OF COMBINED SYSTEMS

needs (Chapter 8). Thus, Phase 2 planning requires the use of all the technical chapters in the manual.

Small communities (up to 3,500 population) do not usually need the same level of planning and investigation that is essential for large systems. Nor do they always need the level of sophistication that is normally provided, in terms of equipment and management procedures, for large systems. Procedures and shortcuts that are unique to small land treatment systems are described in Chapter 7. Typical examples are included to illustrate the level of effort needed in field work and design.

The final design of a land treatment system needs only to draw on the pertinent chapter (4, 5, or 6) for the intended process. Some additional field investigation (Chapter 3) may be necessary to optimize hydraulic loading rates and ensure proper subsurface flow conditions. The design chapters do not present complete detail on the hardware (i.e., pumps, pipe materials, sprinkler rigs, etc.) involved. Other sources will be needed for these design details. The cost information in reference [l] or in the CAPDET program is suitable for planning, comparison of alternatives, and preliminary design only. The final construction cost estimate should be derived in the conventional way (by material take-off, etc.) from the final plans.

Appendixes A, B, and C provide design examples of SR, RI, and OF and are intended to demonstrate the design procedure. Energy budgets and costs are provided along with the process design. Appendix D contains a representative list of currently operating municipal (also federal government and selected industrial) land treatment systems in the United States.

Appendix E provides information on designing irrigation systems for SR facilities. The level of detail in this appendix is sufficient to develop preliminary layouts and sizing for distribution system components. Appendix F contains a list of communities for which the EPA programs that determine storage requirements based on climate (Section 4.6.2) have been run. The final appendix, G, provides a glossary of terms and conversion factors from metric to U.S. customary units for all figures and tables.

The design approach for land treatment has been essentially empirical, i.e., observation of successful performance followed by derivation of criteria and mathematical expressions that describe overall performance. Essentially the same approach was used to develop design criteria for activated sludge and other biological treatment processes.

The physical, chemical, and biological reactions and interactions occurring in all treatment processes are quite complex and are difficult to define mathematically. Such definition is still evolving for activated sludge as well as land treatment. As a result, the design procedures presented in this manual are still conservative and are based on successful operating experience.

More rational design procedures however, are becoming available (see Section 6.11). In addition, there are mathematical models available that may be used to evaluate the response to a particular constituent (nitrogen, phosphorus, etc.) or used in combination to describe the entire system performance. A brief summary of models that are currently available is included in reference [13] . A more detailed discussion of specific models for land treatment can be found in reference [14]

1.9 References

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